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Footdrop Stimulator Controlled by a Tilt Sensor: Neuroprosthesis vs Human-Machine Interaction

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Abstract. Functional Electric Stimulation (FES) is a useful tool for rehabilitation of footdrop as a result of central nervous system damage and also as neuroprosthetics. It was recently proposed a device in which FES is activated by a tilt sensor. During rehabilitation pathway, the parameter setting and human adaptation results in interactive loop that improves the functionality and stability of gait.

Keywords: Functional electrical stimulation, Footdrop, Stroke, Brain Neural Computer Interface, Rehabilitation

1. Introduction

Footdrop, is a quite common problem in nervous system disorders, characterized by a person's inability to dorsiflex the ankle raising the foot. Functional applications of neuromuscular electrical stimulation may be an alternative approach to correct footdrop. The Functional Electrical Stimulation (FES) can be timed with the swing phase of the gait cycle to stimulate the ankle dorsiflexor muscles. Only footdrop resulting from central (and not peripheral) nervous system problems can be treated for the need of integrity of the nerve and muscles is needed for stimulation [Stein et al 2006]. FES improves gait velocity and endurance, and prevents falls [Stein et al 2006]. Stimulating the Common Peroneal Nerve (CPN), FES operates actively in the ankle dorsiflexion and strengthens the muscle. In our study we investigate the use of a commercial stimulator using a tilt sensor (WalkAide), which measures the orientation of the shank, controlling when turn the stimulator on and off [Weber et al 2004]. During set-up phase, manual controller and a heel sensor pressure data were collected and connected to the rest of electronics both by a telemetry link. Analyzing data obtained in the set-up phase and matching them with the rehabilitative purpose we can choose useful tilt parameters to correct footdrop. Recently it has been shown that the use of FES for 3 months increases the maximum voluntary contraction and motor evoked potentials [Everaert et al 2010]. In fact, footdrop stimulator might enhance cortical reorganization and improve motor outcomes. The first aim of this study is to clarify if this device should be intended only as a neuroprosthetics, or if it needs a human-machine interaction for a progressive adaptation of the device parameter values to the patient and vice versa. The second aim is to evaluate the changes in trunk dynamic stability before and after a FES training to footdrop.

2. Material and Methods

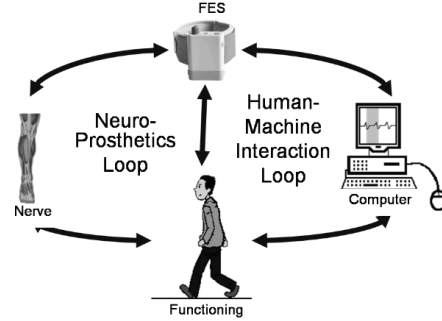
Five patients with foot-drop due to stroke in subacute phase were enrolled in this pilot study. Their mean age was 51 ± 14 years. Two of them usually used rigid ankle-foot orthosis to correct drop foot and they used it also during the test-control sessions. They received 6 weeks rehabilitation treatment with 1 session of WalkAide lasting 1 hour per day, 5 days per week. Each week an adjustment of the walkaide parameters was performed during a specific training session using. The computer software modifies the parameters in accordance to the results of an adjunctive heel sensor of pressure for foot strike determination. However, when needed further modifications were done by the therapist. This process formed the Human Machine Interaction Loop also represented in Figure 1. At the end of the first session of treatment the ten meters walking test (10MWT) was performed by the patients. Participants were asked to stay on a line marked on the floor and, after an acoustic signal, to walk

forward for 10m to a second line, with aid if needed, in a 20m-long laboratory. They dressed an elastic belt including a wireless triaxial accelerometer (FreeSense®, Sensorize s.r.l., Rome; fsampling=100Hz) collocated on the back in correspondence of L2-L3, close to the body mass centre. The Root Mean Square (RMS) of the accelerometric signal (a_i) was evaluated along the three body axis (Antero-Posterior AP, Latero-Lateral LL, Cranio-Caudal CC). During walking at constant speed the mean acceleration should be null, the RMS coincides with the standard deviation of signals. Then, it was normalized by dividing it by the walking speed and multiplying it for the step frequency. The Harmonic Ratio (HR) was evaluated after Fast Fourier Transform in which the first 4 harmonics and it is an index of gait harmonicity. It was computed as it follows (i is = 2 and 4 for AP and CC, and 1 and 3 for LL, and the contrary along LL)

$$HR = \sqrt{\sum_{i=1}^n A_i / \sum_{j=1}^n A_j} \quad (1)$$

Both the RMS and HR were computed as the mean RMS and HR on three strides performed in the middle of walking pathway. Accelerometer was also used to evaluate the time spent to perform the 10mWT (T), the mean walking speed (WS), the mean step length (SL), the mean stride frequency (SF).

Figure 1. On the left the Neuro-Prosthetics loop that connects Functional Electrical Stimulator (FES), nerve and functioning. On the right the Human-Machine Interaction Loop in which the computer was used for the patient's training and FES-parameter adjustment.



3. Results

The results for the five patients are summarized in Table 1. The use of WalkAide increased the step length (SL), but also increased the stride frequency (SF), resulting in a slight increase of walking speed. WalkAide did not alter the upper body stability, but it increased the LL and CC harmonicity of walking, but not that in AP. After training, step length increases, stride frequency decreased and walking speed increased with and without WalkAide. The normalized RMS of acceleration did not vary along training. The Harmonic Ratio was increased after training, but in latero-lateral direction it was preserved only using WalkAide.

Table 1. Results before and after training of test without (No WA) and with WalkAide (WA)

Training		T [s]	SL [cm]	SF [1/s]	WS [m/s]	a-AP [m/s ²]	a-LL [m/s ²]	a-CC [m/s ²]	HR AP	HR LL	HR CC
Pre	No WA	40±20	34±8	0.49±0.21	0.34±0.21	0.7±0.2	0.9±0.4	0.8±0.4	1.3±1.3	2.3±1.3	2.2±1.5
	WA	45±24	35±14	0.51±0.21	0.35±0.29	0.7±0.2	0.8±0.2	0.8±0.6	1.0±0.6	2.5±0.8	2.4±2.5
Post	No WA	34±17	43±13	0.47±0.27	0.40±0.27	0.7±0.2	0.9±0.2	0.9±0.6	2.0±1.4	1.6±1.1	3.4±1.7
	WA	33±17	43±14	0.47±0.25	0.41±0.29	0.8±0.2	0.9±0.2	0.9±0.5	1.8±1.5	2.3±1.4	3.9±2.9

4. Discussion

Neuroprosthetics typically connect the nervous system to a device. WalkAide is a new type of FES that seems to allow greater control of the plan treatment and to be more user friendly. In fact, after training with WalkAide, the gait rhythmicity is higher and more functional than before, both with and without it. Our results also showed the need of human-machine interaction in which device parameters are updated in order to follow the motor recovery. Moreover the signals from implanted prostheses can, after adaptation, be handled by the brain like natural sensor and effector channels. This approach might help to reach a complete restore of corrected neural links from brain to muscles. Further studies should be performed on wider samples including a control group to verify the efficacy of this approach.

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